<u>Science and Engineering: a perspective on distinct disciplines</u>

I am a life scientist. My work can be symbolized as a black box with a question mark. I am curious, I inquire about things, and I ask questions with a common beginning: **I wonder how**…, **I wonder why**..., **I wonder where**…, **I wonder if**… but I don't receive many solid answers. Nature doesn't surrender them easily. I am a cell biologist, and I work among a community of colleagues who also begin each and every day with a question of their own. Some ask how cells migrate, some wonder how cells divide, some study how cells differentiate, while others probe how cells sense and respond to their environment. What do I do? I study how and why cells can prematurely age, dramatically shortening life span and causing severe health consequences as they do.

Science is an inquiry-based discipline. Scientists often spend their careers pursuing a single inquiry, and likewise a simple question (how do cells age?) can seed an expansive field of study that will ultimately consume many researchers for decades.

Scientists follow a procedure called the **scientific method**. The scientific method is the foundation of the ***hypothesis-driven inquiry based*** discipline that is science. As scientists we ask questions, we seek to understand, we interpret our observations, we **formulate a hypothesis** (an explanation for what we observe), we **test a prediction** (one that can be determined to be true or false) that follows from our hypothesis by performing experiments, we **interpret the data** we gather as supporting or negating our hypothesis, we **formulate new hypotheses or revise old ones** as needed, and then we test new or additional hypothesis-driven predictions. It is a never-ending process that, regardless of the data/clues obtained, contributes to our knowledge of the natural world. The output of the scientific method is not a tangible product, but rather a wealth of accumulated knowledge. This knowledge is stored in published literature and databases that are available for all to access, interpret, utilize, apply, or expand upon.

My brother is in the field of engineering. Engineers do not spend their days wondering, asking, and acquiring knowledge about the natural world. ***Engineering is not a hypothesis-driven inquiry based discipline.*** An engineer is guided by practical challenges and demands posed to them from various sectors including private citizens, industry, government agencies, and science. The challenges and demands that engineers face each and every day derive from statements such as **I need**... (a suspension bridge and better designed highways), **I want**... (a fuel efficient car, a space probe that can orbit Mars), and **I wish I had**... (a confocal laser scanning microscope capable of high throughput cellular imaging, a computer program to perform high level meta analyses).

Engineers have defined goals that they must achieve and products that must be produced to meet certain criteria. An engineer must conform to design specifications and practical and theoretical constraints in order to produce a desired output. At the end of a day's, a week's, a month's or a year's work, they have a tangible result that fulfills a need, facilitates a process, or serves a purpose, whether it is a new bridge to improve traffic flow, a space probe capable of orbiting Mars, a hybrid fuel efficient car, a computer program that can analyze and validate a large quantity of biological data, or a high throughput confocal laser scanning microscope that aids in scientific inquiry about living cells.

So by what method or process do engineers perform their daily work? Engineers are task-oriented. They are highly skilled ***design planners, problem solvers, and solution strategists***. They do not engage in questioning or formulating abstract hypotheses or running on the treadmill of knowledge-seeking that defines and dominates the scientific endeavor. Thus the method by which they accomplish their work is **fundamentally different from the scientific method that is used by scientists**. Engineers use a methodology called the **"engineering process"**. Engineers receive a request, a demand, or a challenge to innovate or improve upon a product. They prepare a **design plan** that incorporates any required specifications and criteria. They perform **prototype building, iterative and repetitive testing** (which can involve trial and error), and **design modification**, until the desired outcome is met and a final product has been achieved.

Science and engineering are not mutually exclusive disciplines. Our disciplines are distinct, but they are ***highly dependent on one another for the success and advancement of each***. Each and every day I spend in the laboratory I use the products of engineers, designed to help me image and study cells. I use ultra-centrifuges, laser scanners, spectrophotometers, multi-well plate readers, film processors, digital imaging devices, confocal laser scanning microscopes, sonicators, computer software programs, and gel documentation devices. Without engineering technology, which encompasses the most basic homemade microscope to the most advanced laser scanners, the very nature of my job would not be possible. Likewise, such devices were successfully engineered by applying knowledge gained from the scientific endeavor. Engineers brainstorm, consider, harness, apply, and incorporate our accumulated knowledge of physical, material, chemical and molecular properties into the design of the devices that we use.

Scientists and engineers face every working day with a different methodology, each designed to best help us achieve different goals. As a scientist my goal is to pose questions and gain knowledge about life. It is to inquire, suggest and revise questions, all of which lead to achievements that can be witnessed as published manuscripts, measured as an expansion of our knowledge, and applied to the treatment and prevention of human diseases. Meanwhile, an engineer's job is to problem-solve, create, fix, strategize, and apply our accumulated knowledge to achieve solutions. To truly understand science and engineering, and the interface between them, is to realize that they are distinct, yet highly interdependent disciplines.

To those charged with educating our students about science and engineering, and to those who guide our students along various paths of discovery, falls a very important task. We must teach our students the difference between the disciplines of science and engineering, what the goals of each discipline are, and how the methods employed in these disciplines differ. For the students engaging in science and engineering fair projects, we must enable them to know the difference between a scientific inquiry and an engineering challenge. Do they seek to answer a question about the world they inhabit, or do they accept a challenge to design, build or create a useful product, computer program, or invention? With the ability to distinguish these types of activities, students can learn and utilize the appropriate method to accomplish and present their work to an audience. A fundamental understanding of the science and engineering disciplines that advance our society is an important educational requirement, and must be communicated and promoted by informed dialogue between students, teachers, scientists, and engineers. This dialogue is critical for our educational success, and for the promise and future of our scientific and engineering endeavors.

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Jemima Barrowman earned her doctoral degree at Yale University, where she studied the molecular mechanisms of protein trafficking. She completed her post-doctoral training at the Johns Hopkins School of Medicine in Baltimore, MD where she studied the cellular mechanisms involved in premature aging diseases, and investigated their potential connection to disorders such as cardiovascular disease that are present in the normally aging population. She is currently a science writer at the National Institutes of Health in Bethesda, MD.

Her brother, Kristian Barrowman, is an engineering technologist who works for Teradyne Corporation in Essex Junction, VT. His professional duties include maintaining, installing, and repairing semiconductor test equipment for the world's most advanced microchips.